

Condition and recruitment of *Aristeus antennatus* beyond fishing ground (to depths of 2200 m) in the Mediterranean: relationship with environmental factors

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The red shrimp *Aristeus antennatus* is likely the most important target species in deep sea fisheries in the Mediterranean. Most of the large amount of biological information available for *A. antennatus* come from commercially exploited depths (e.g. Relini-Orsi and Pestarino 1981, Demestre and Fortuño 1992, Carbonell *et al.* 2006), whilst beyond commercial depths, where we find an important part of the population, e.g. > 1000 m in the deep Mediterranean, studies are still largely incomplete, with a practically nonexistent seasonal sampling.

The aim of this study was to analyze the spatial and temporal variability of *A. antennatus* along its entire depth distribution in the Balearic Basin (to 2200 m depth), identifying variables that control its biological cycle. For this, we analyzed:

- 1) Seasonal and spatial changes of hepato-somatic, gonado-somatic indices and of the density of smallest juveniles (ca. 1 yr age, Cartes and Demestre 2003);
- 2) The environmental variables (temperature, salinity, particulate organic matter, POM, dissolved oxygen) that control *A. antennatus* habitat.

Such approach has hardly attempted in deep-sea biology and results obtained can therefore be applicable to the study and management of *A. antennatus* and other deep sea species.

Depth trends relationships of GSI and HSI

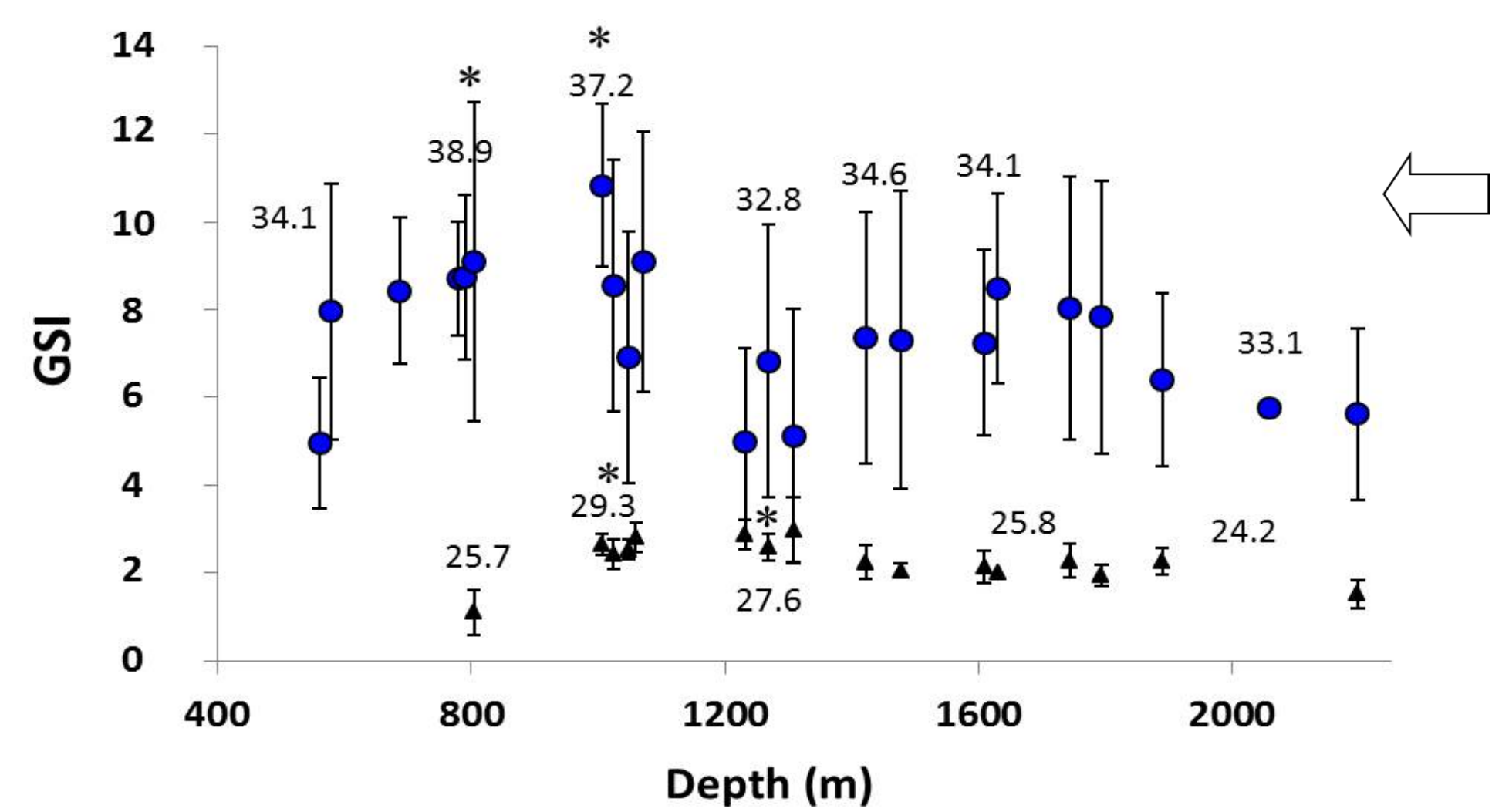


Figure 3. Average GSI for females (●) and males (▲) of *A. antennatus* (with SD) vs depth along the Balearic Basin. Numbers represent mean sizes of specimens; asterisks (*) are significant differences in mean sizes between contiguous groups.

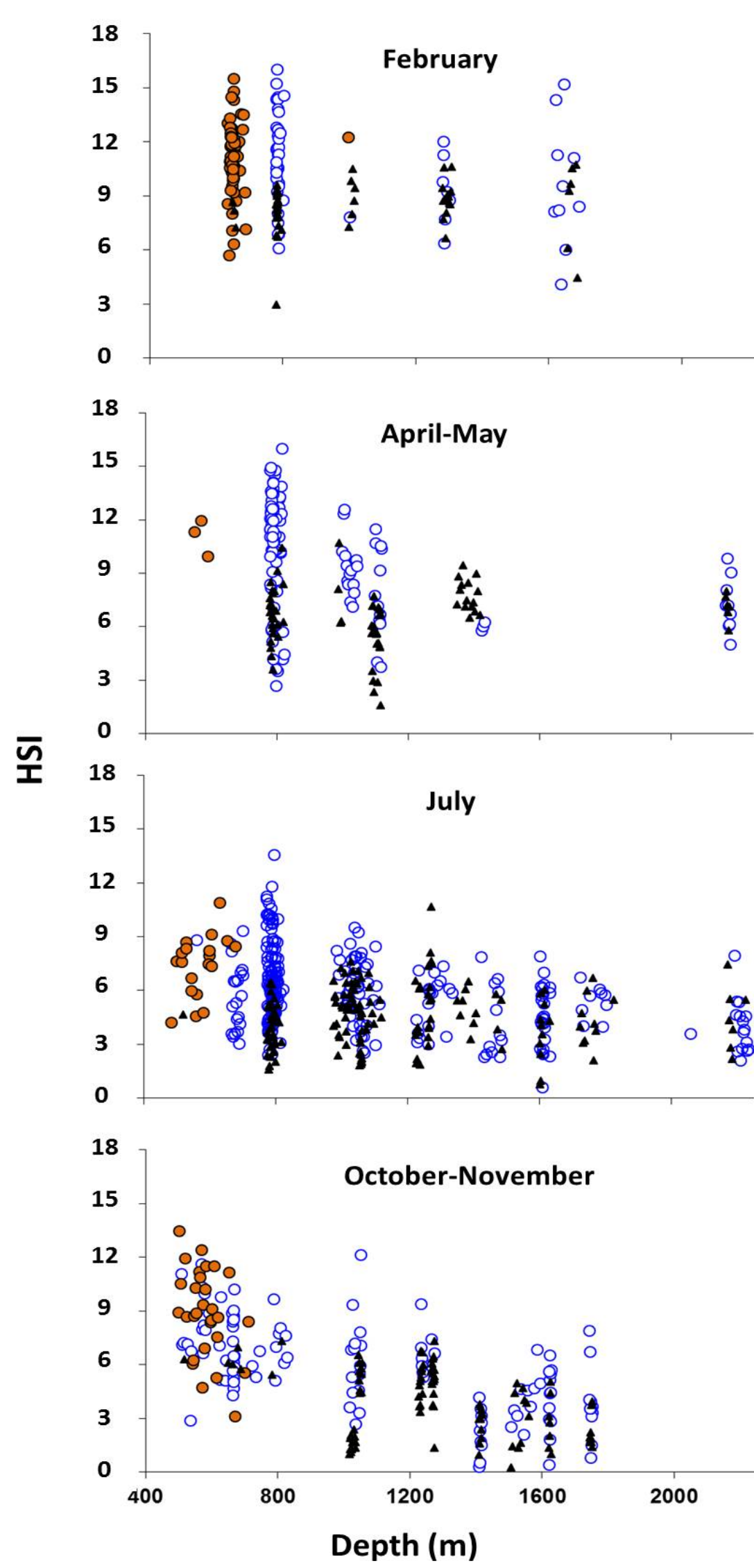


Figure 4. HSI for females (●, ○) and males (▲) in the Balearic Basin. Full circles are adult females collected into submarine canyons.

Environmental gradients and trophic relationships

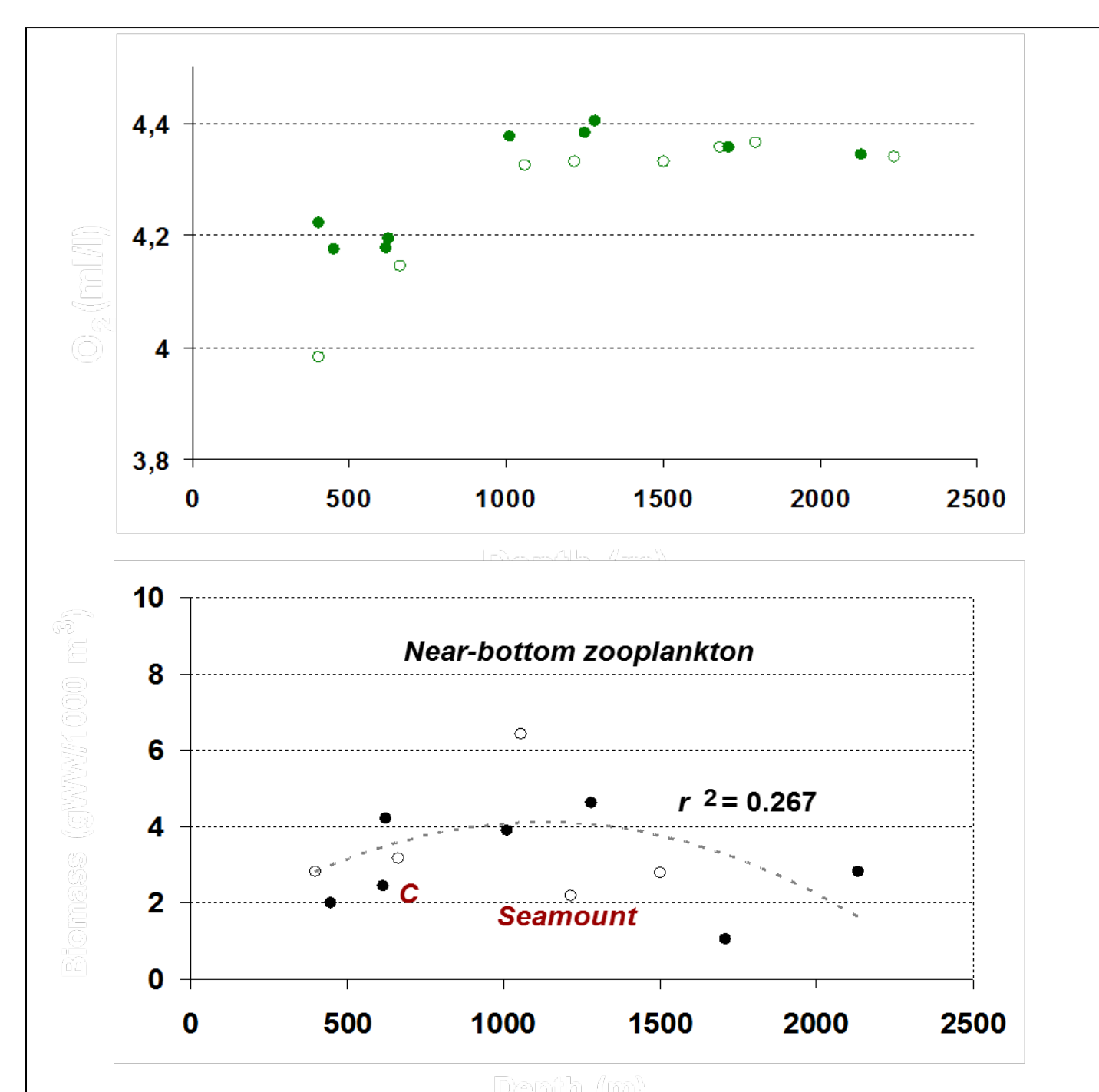


Figure 5. Concentration of dissolved oxygen near the bottom (at 5 m above) increase at > 1000 m in the Balearic Basin (upper), below Levantine Waters (LIW) influence. At 1000-1300 m, where O_2 peaks, it has also been recorded highest biomass of near-bottom zooplankton (Cartes *et al.* 2013). Such conditions may enhance *A. antennatus* recruitment.

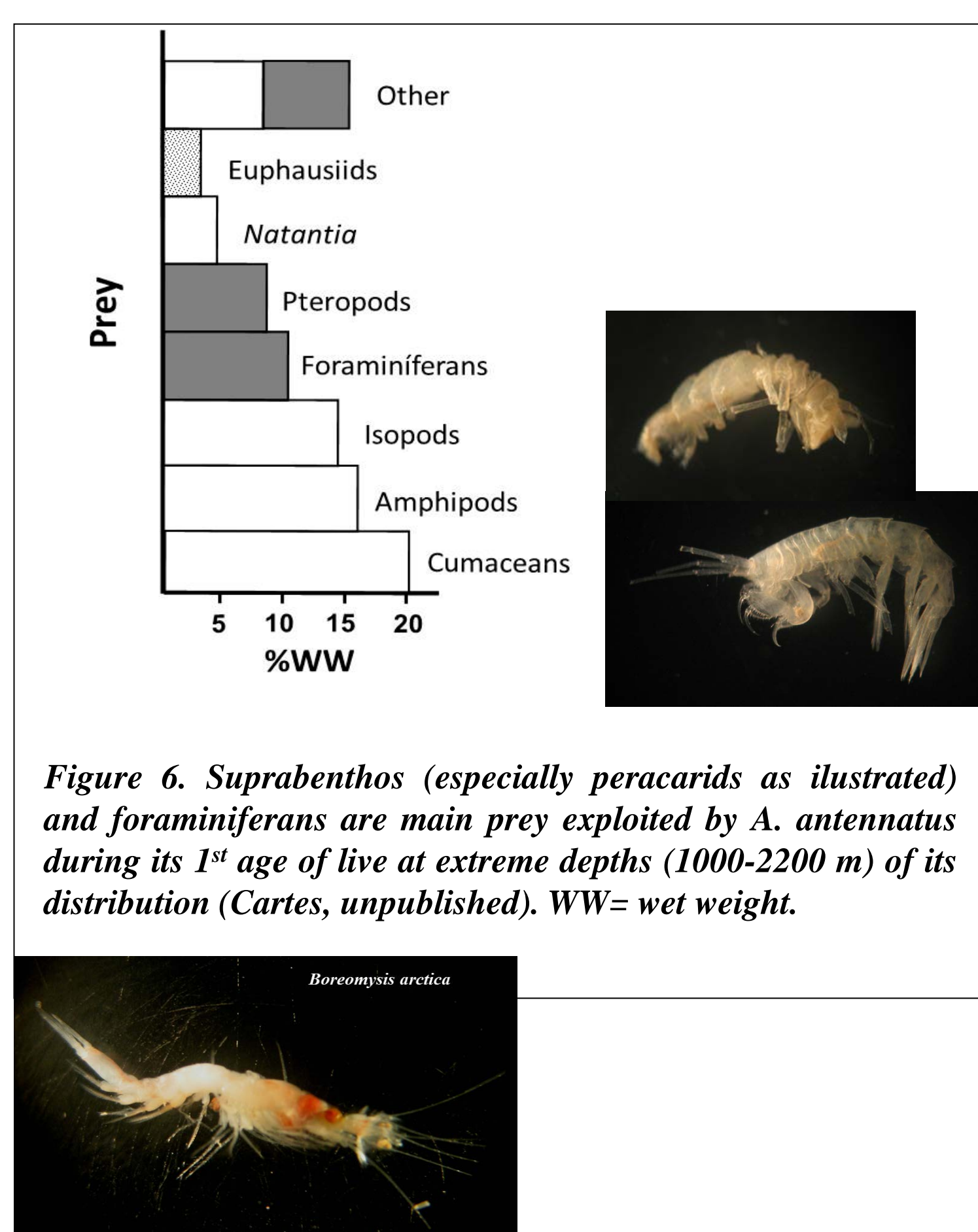


Figure 6. Suprabenthos (especially peracarids as illustrated) and foraminiferans are main prey exploited by *A. antennatus* during its 1st age of live at extreme depths (1000-2200 m) of its distribution (Cartes, unpublished). WW= wet weight.

The study area comprised the Balearic Basin (between Catalonia coasts and the Balearic Islands, Figure 1), in the NW Mediterranean: sampling was performed on muddy bottoms on mainland and insular slope areas.

Nine surveys were performed between 2007 and 2012, from 427 to 2233 m. An OSTB-14 bottom trawl, standard gear for study of deep-sea megafauna (Cartes *et al.*, 2008) was used in the majority of hauls performed (71 of a total of 80 hauls), with some additional commercial hauls. Densities are calculated on the former, so they are comparable, e.g. among depths/seasons. Hauls were performed over the entire Balearic Basin covering fishing grounds (to ca. 900 m depth) and deeper depths free of trawling activity.

Sampling is unique in the deep Mediterranean, covering seasonality to depths of 2200 m. However, we presented results after we built a virtual year, due to logistic constraints. This composite year (2007 to 2012) is reasonable to analyse shrimp's biology, because reproduction of *A. antennatus* in a same area is known to occur in the same season year after year (Carbonell *et al.* 2006, Figure 2).

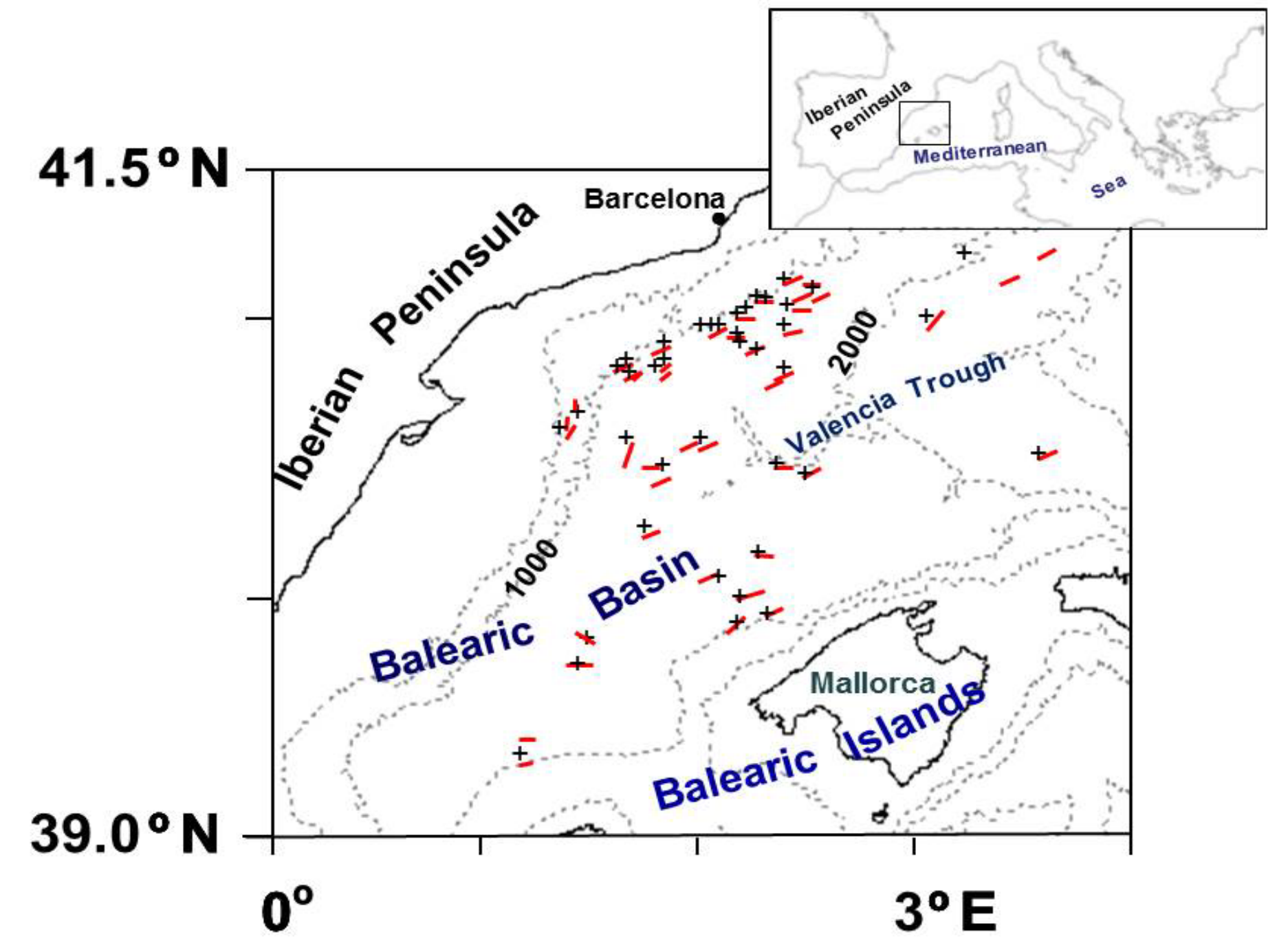


Figure 1. Location of hauls in the Balearic Basin, indicating bottom trawls (---) and CTD profiles and Multicorer samples (+) performed to collect environmental data in the near-bottom water column.

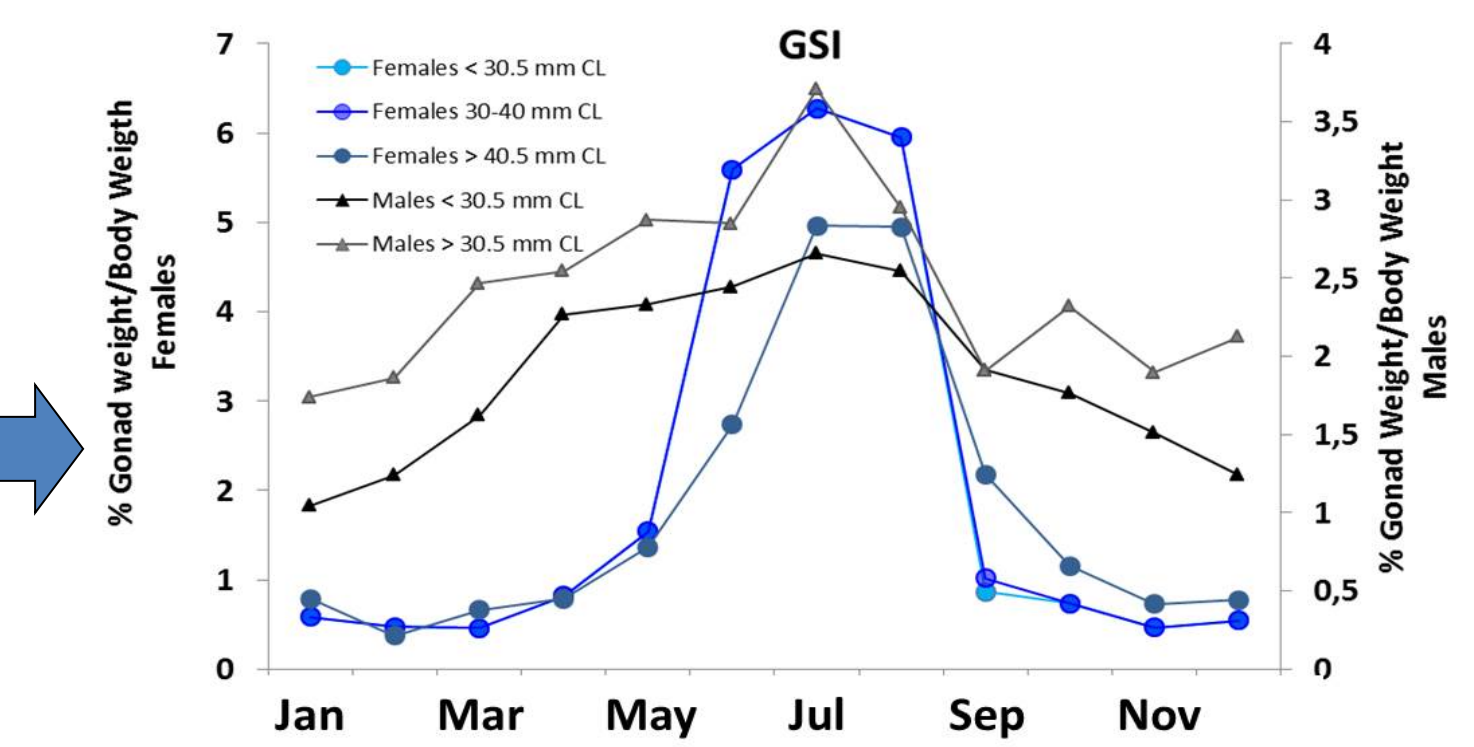


Figure 2. *A. antennatus*: Mean monthly GSI of males and females of different stages of maturity collected throughout an annual cycle off Mallorca Island over depths of 600-800 m, integrating the period 1991-2010.

Recruitment of small juveniles

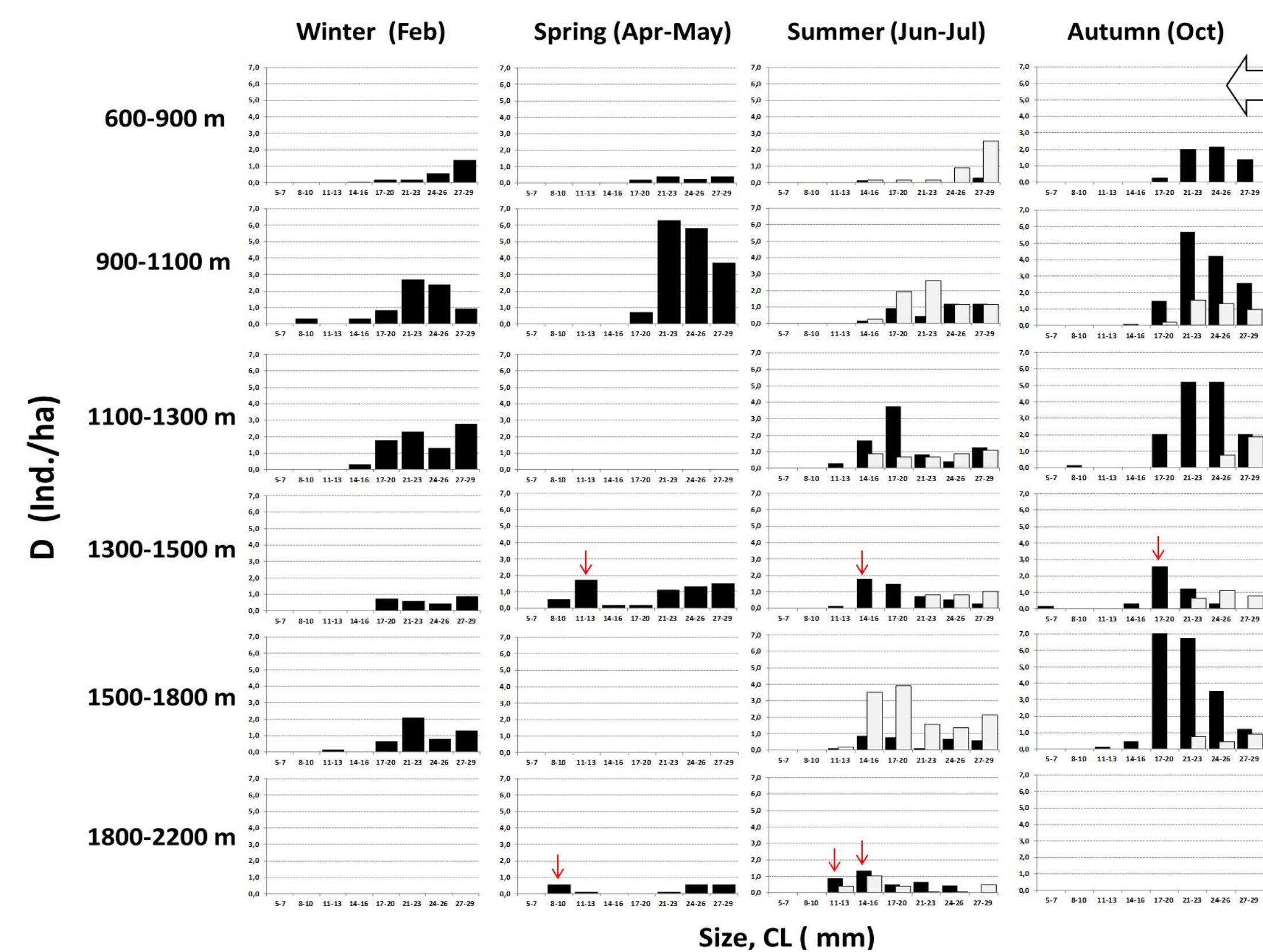


Figure 7. Size-distribution (CL mm) of *A. antennatus* recruits by depth interval in the Balearic Basin.

- The smallest juveniles of *A. antennatus* (6 mm CL) were collected at 1300-1500 m in October (only few specimens).
- Peaks of small juveniles (red arrows in Figure) appeared in spring (April-May) at 1300-1500 m and 1800-2200 m.
- These April-May recruits developed from the spawning of the previous year (June to September), so they were ca. 1 yr aged.
- Recruit peaks persisted in summer (July), growing at 1300-1500 m from 11-13 mm CL (May) to 14-16 mm CL in July.
- Similar size increments occurred at 1800-2200 m.

Environmental analysis

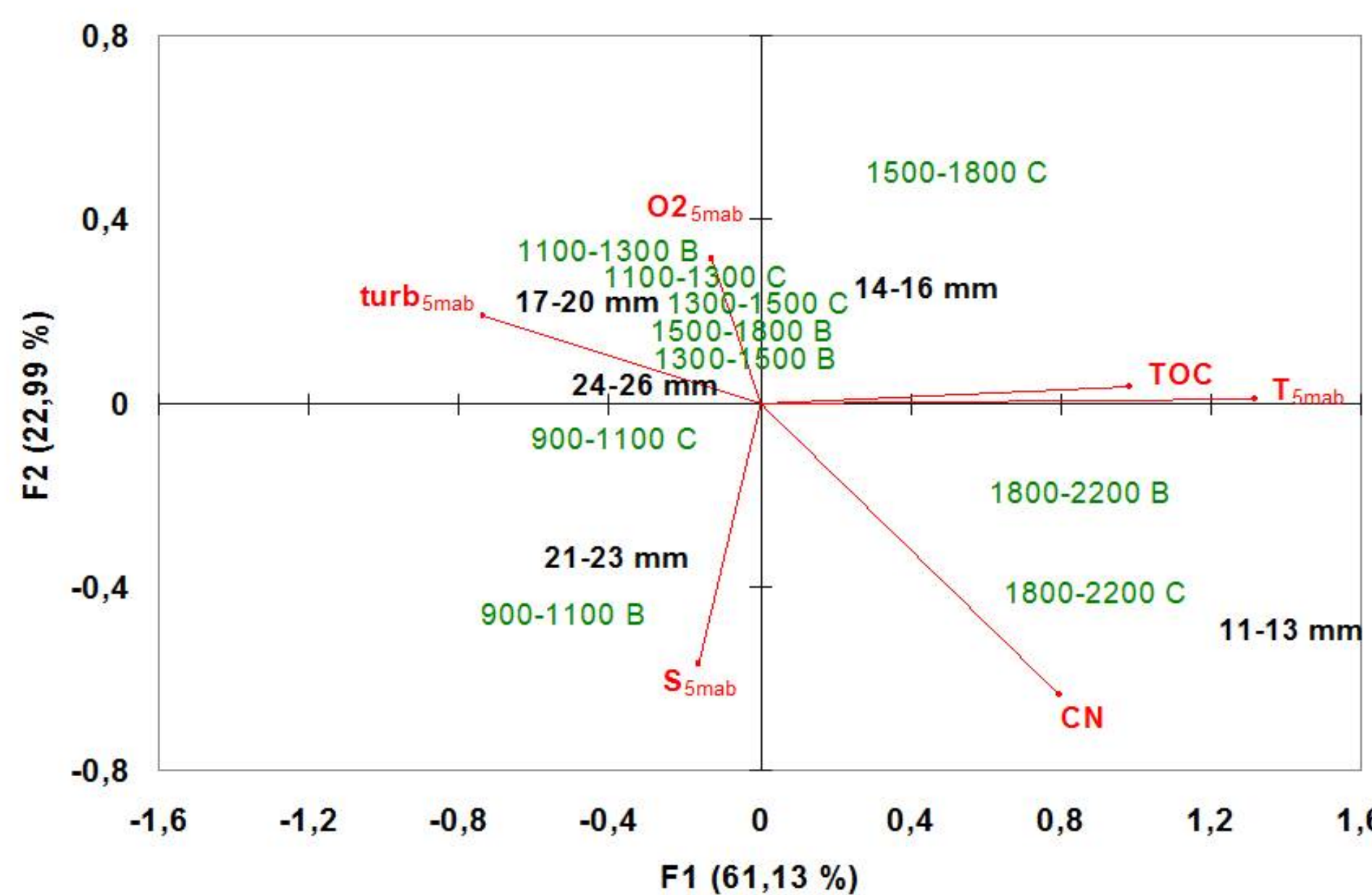


Figure 8. CCA for size classes of small *A. antennatus* by depth interval in the Balearic Basin and relationship with environmental near-bottom and sediment variables. T: temperature; S: salinity; turb: turbidity; TOC: Organic Carbon; CN: C vs N ratio.

CCA relationships between small juveniles of *A. antennatus* (CL < 26 mm) and the environmental variables in each depth-stratum (off Catalonia, C, and insular slope off Balearic Islands, B) were:

- Juveniles of 11-13 mm CL were mainly linked to higher C:N and TOC in sediments, at 1800-2200 m, both at C and B.

- At 1100-1500 m, and deeper to 1800 m in the insular part, juveniles of 14-19 mm CL occupied depth strata with higher near-bottom turbidity and greater O_2 concentration.

- The finding of high reproductive condition of *A. antennatus* at depths of 800-1300 m in the Balearic Basin, below fishing grounds, indicates what important is to study the biology of deep-sea species, especially those submitted to fishery pressure, over their whole depth range and not only on the fishing grounds.
- The simultaneous study of shrimps, of habitat variability and prey availability over the full life-cycle depth range allows explanation of reproductive, growth and recruitment patterns. For example, the exclusive distribution of recruits (age ca. 1 yr) at > 1000 were linked to best food availability in sediments and higher near-bottom turbidity and O_2 concentration.
- Aggregation of small juveniles occurred both over the Catalan (mainland) and Balearic (insular) slopes (see Figure 7). So, near-bottom recruitment in the 1st year of live follows basically the same pattern all around the Balearic Basin. Also, reproductive animals migrate seasonally from upper part of canyons (500-600 m) to depths > 1000 m. All this movements indicates high short-term dynamism within the population, suggesting that we do not have distinct meta-populations of *A. antennatus* in the Balearic Basin.
- All these findings may contribute to the optimal management of *A. antennatus* fisheries, especially given an increasing tendency by the fleets to fish deeper, moving to depths where the species preferently are mating and spawning, over the lower slope.

References

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